State of the Art in Grouting

Dams on Solution Susceptible or Fractured Rock Foundations

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Track 6

- Overview of USACE dams on solution susceptible or fractured rock foundations
- Special drilling and grouting techniques for remedial work in embankment dams
- Composite grouting and cutoff wall solutions
- State of the art in grout mixes
- State of the art computer control, monitoring and analysis of grouting
- Quantitatively engineered grout curtains
Solution Susceptible Rock Foundation

Indiana Limestone
Solution Susceptible Rock Foundation

Indiana Limestone
Solution Susceptible Rock Foundation

Boone Formation
Beaver Dam, AK
Fractured Rock Foundation
Fractured Rock Foundation

Western Maryland
Rock Foundation at Clearwater Dam
Fractured Rock Foundation
Basic Technical Requirements for an Embankment Dam

- Must have sufficient spillway and outlet capacity as well as adequate freeboard to prevent overtopping by the reservoir
- Must be stable under all loading conditions
- Dam and “foundation” must be sufficiently watertight and have adequate seepage control for safe operation
Causes of Dam Failures in the United States
Embankment Dams *

<table>
<thead>
<tr>
<th>Cause</th>
<th>1955</th>
<th>Current</th>
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<tbody>
<tr>
<td>1. Inadequate spillway capacity</td>
<td>30%</td>
<td>40%</td>
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<tr>
<td>2. Seepage/piping</td>
<td>25%</td>
<td>37%</td>
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<td>3. slides</td>
<td>15%</td>
<td>6%</td>
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<td>4. Conduit leakage</td>
<td>13%</td>
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<td>5. Slope protection</td>
<td>5%</td>
<td>17%</td>
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<tr>
<td>6. Unknown</td>
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* Source – National Inspection of Dams Program, Corps of Engineers survey and Bureau of Reclamation survey
Corps of Engineers Dams

569 Total dams (2000)

Concrete
28%

Embankment
72%

407
Corps of Engineers Embankment Dams by Hazard Classification & Spillway Operation

407 Embankment

- 356 High hazard
  - 243 ungated *
  - 113 gated

- 36 Significant hazard
  - 24 ungated *
  - 12 gated

- 15 Low hazard

* Flood control loading in feet of head is greatest for ungated dams
Total Loading History
High Hazard Ungated Dams
as of 2000

41 of the 243 have experienced spillway flow
Uplift in Rock and Seepage

Reservoir at 35% storage capacity
## Summary of 1976 HQ Survey

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**USACE Total**: 35 Solution, 4 Fractured, 7 Both
Some Recent Corps Experiences with Existing Dams That Required or will Require Modification

- Hartwell Dike, SC – cutoff wall
- Beaver Dam, AK – secant pile cutoff
- Patoka Dam, IN – grouting
- Mississineau Dam, IN – grouting and then panel wall
- Walter F. George, GA – grouting with panel wall
- Clearwater Dam, AK – emergency grouting then permanent grouting and then cutoff wall
- Wolf Creek, TN – report with recommendations being submitted to headquarters
Considerations in Selecting the Type of Cutoff for Seepage Control

- Exploration and investigations
- Site characterization
- Physical properties of the fractured or solution susceptible rock foundation
- Establishing the depth and length of cutoff
- Contracting procedure

IFB, RFP and Best Value
Conventional Grouting

Dipstick measurements

Mechanical gages and manual monitoring

Time consuming manually prepared charts
RESULTS ??

General Impression of Conventional Grouting
Recent Development in Grouting Materials, Equipment and Procedures

1. Drilling and grouting techniques
Recent Development in Grouting Materials, Equipment and Procedures

2. State of the art Grout mixes

Neat Cement

Balanced Stabilized
Recent Development in Grouting Materials, Equipment and Procedures

2. State of the art Grout mixes

Computer controlled batch plant
Recent Development in Grouting Materials, Equipment and Procedures

3. Composite grouting and cutoff walls
Recent Development in Grouting Materials, Equipment and Procedures

4. State of the art computer control, monitoring and analysis of grouting
5. Quantitatively engineered grout curtains

- Evaluation of geologic conditions
- Detailed site characterization
- Design of grout curtains as an integral part of the project to achieve specific results
- Best value contracting
Summary

Establishing the initial or remedial seepage cutoff for a water resources project can be difficult, expensive and requires monitoring and future evaluation.

Recent advances in grouting technology, materials, practices and procedures have made multiple line grouting a reliable and cost effective method to control seepage or the flow of groundwater.
Critical Information for Flood Control Operation of Dams

- Inflow predictions
- Projected reservoir levels
- Corresponding storage
- Predicted performance of the dam and structures
- Threshold for changes in monitoring program
- Threshold for potential operational changes due to structural performance
- Draw down capability
  - with full bank discharge capacity
  - with full discharge